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Patty X. Kuo

University of Notre Dame, pkuo2@unl.edu

Julia M. Braungart-Rieker

University of Notre Dame, jbraunga@nd.edu

Jennifer E. Burke Lefever

University of Notre Dame, jennifer.e.burke.42@nd.edu

Mallika S. Sarma

University of Notre Dame, msarma@nd.edu

Molly O'Neill

University of Notre Dame, moneil11@nd.edu

See next page for additional authors

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Authors

Patty X. Kuo, Julia M. Braungart-Rieker, Jennifer E. Burke Lefever, Mallika S. Sarma, Molly O'Neill, and Lee T. Gettler

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Fathers' Cortisol and Testosterone in the Days around Infants' Births Predict Later Paternal Involvement

Patty X. Kuo,^{1,2,a} Julia M. Braungart-Rieker^{2,3} Jennifer E. Burke Lefever,²

Mallika S. Sarma,¹ Molly O'Neill,³ and Lee T. Gettler^{1,2,4,a}

1. Department of Anthropology, University of Notre Dame, Notre Dame, Indiana, USA
2. William J. Shaw Center for Children and Families, University of Notre Dame, South Bend, Indiana, USA
3. Department of Psychology, University of Notre Dame, Notre Dame, Indiana, USA
4. The Eck Institute of Global Health, University of Notre Dame, Notre Dame, Indiana, USA

a. Patty X. Kuo and Lee T. Gettler contributed equally to this work.

Corresponding authors – Patty X. Kuo and Lee T. Gettler, Department of Anthropology, 244 Corbett Family Hall, Notre Dame, IN 46556, USA, email pkuo@nd.edu and lee.t.gettler.1@nd.edu

Abstract

Human paternal behavior is multidimensional, and extant research has yet to delineate how hormone patterns may be related to different dimensions of fathering. Further, although studies vary in their measurement of hormones (i.e., basal or reactivity), it remains unclear whether basal and/or reactivity measures are predictive of different aspects of men's parenting. We examined whether men's testosterone and cortisol predicted fathers' involvement in childcare and play with infants and whether fathers' testosterone and cortisol changed during fathers' first interaction with their newborn. Participants were 298 fathers whose partners gave birth in a UNICEF-designated "baby-friendly" hospital, which encourages fathers to hold their newborns 1 h after birth, after mothers engage in skin-to-skin holding. Salivary testosterone and cortisol were measured before and after fathers' first holding of their newborns. Basal and short-term changes in cortisol and testosterone were analyzed. Fathers were contacted 2–4 months following discharge to complete questionnaires about childcare

involvement. Fathers' cortisol decreased during the time they held their newborns on the birthing unit. Fathers' basal testosterone in the immediate postnatal period predicted their greater involvement in childcare. Both basal and reactivity cortisol predicted fathers' greater involvement in childcare and play. Results suggest that reduced basal testosterone is linked with enhanced paternal indirect and direct parenting effort months later, and that higher basal cortisol and increases in cortisol in response to newborn interaction are predictive of greater paternal involvement in childcare and play, also months later. Findings are discussed in the context of predominating theoretical models on parental neuroendocrinology.

Keywords: hormones, psychobiology, fatherhood, paternal care, newborns, endocrine reactivity

1. Introduction

Mammalian mothers experience a host of hormonal changes during pregnancy that prime maternal behaviors after giving birth (Mileva-Seitz and Fleming, 2011; Numan and Insel, 2003). In contrast, mammalian males do not experience the same physiological changes caused by pregnancy and lactation. However, among species in which fathers care for young, some changes in mammalian males' basal hormone levels during the transition to fatherhood are linked with paternal behaviors (Saltzman and Ziegler, 2014; Storey and Ziegler, 2016) and appear to be preparatory or experience-dependent (Numan and Insel, 2003). In particular, testosterone (T) has been widely studied in relation to paternal behavior (Gettler, 2014, 2016; Gray et al., 2017; Rilling, 2013) because of longstanding evidence documenting lower T in conjunction with monogamous mating and parenting effort in male birds (Wingfield et al., 1990). In humans, men transitioning to invested fatherhood experience declines in T, and lower T is associated with greater involvement in childcare (Gettler et al., 2011b). During their partners' pregnancies, fathers also experience declines in basal T, which are predictive of greater involvement in infant care (Edelstein et al., 2017) and partner investment (Saxe et al., 2017).

Although T has been a central focus of the "hormonal basis of fathering" research, particularly in humans, other hormones such as oxytocin, vasopressin, and prolactin have been implicated in the nature of father-child bonding, such as father-child synchrony (Feldman, 2012c; Gettler, 2014; Gray et al., 2017; Rilling, 2013; van Anders et al., 2011), but less so in men's parenting effort, often operationalized in this literature as involvement in childcare (Abraham et al., 2014; Gettler et al., 2015). Cortisol (CORT) is an additional hormone that has been relatively under-studied in relation to paternal behavior but may relate to men's parenting effort. Short-term increases in CORT help to shuttle energetic resources to tissues throughout the body and enable cognitive and behavioral responses to stress (Sapolsky, 2000). Because caring for infants and young children is often described as highly stressful (e.g., with feelings of unpredictability and lack of control) and taxing (Brady and Guerin, 2010; Deater-Deckard and Scarr, 1996), parents' HPA axis is potentially often activated, which could have deleterious effects as a chronic exposure but may also play a role in reinforcing patterns of new behaviors to focus attention toward the infant. Indeed, mothers' elevated CORT in the postpartum period is positively associated with maternal approach behaviors and positive attitudes toward infants (Mileva-Seitz and Fleming, 2011).

and greater interest in infant cues (Fleming et al., 1997). In this paper, we focus on how T and CORT may both predict fathers' involvement in childcare with infants and how T and CORT change during early father-infant interactions.

An unanswered question in understanding the role of hormones in paternal behavior is seemingly contradictory associations between paternal behaviors and basal and reactivity hormone measures, often operationalized as hormone changes during parent-infant interactions. For example, multiple studies have failed to find an association between basal T with parenting quality, but others have observed negative associations between T reactivity and parenting quality (Dorius et al., 2011; Endendijk et al., 2016; Kuo and Gettler, 2019; Kuo et al., 2016). Two different theoretical frameworks have been commonly used to model relationships between reactivity and/or basal measures and paternal behaviors.

According to the biobehavioral synchrony model, hormonal and behavioral cues are exchanged during dyadic parent-infant interactions that create a pattern of behavioral responding (Feldman, 2012a, b). Specifically, biobehavioral synchrony between parent and infant develops via repeated exchanges of affective, physical, and gaze-matching behaviors, which correspond to matching of hormonal systems between parent and infant. Mothers benefit from preparatory physiological and hormonal changes and physical experiences during pregnancy to aid in the development of biobehavioral synchrony. Recent research suggests that for some fathers their physiology likewise begins to shift during their partners' pregnancies (Edelstein et al., 2017; Saxbe et al., 2017), raising intriguing questions about what might precipitate these changes, given fathers' more constrained sensory/physical connections with their unborn babies. That said, based on this conceptual model, it is held that fathers develop biobehavioral synchrony through experiences with the infant after the birth (Feldman, 2012a, b). Thus, within this theoretical perspective, men's hormone changes during early interactions with their infants may shape later patterns of paternal behavior. Although previous research has investigated whether fathers' T (Gettler et al., 2011a; Gray et al., 2007; Kuo et al., 2016; Storey et al., 2011) and CORT (Gettler et al., 2011a; Gray et al., 2007; Saxbe et al., 2014; Storey et al., 2011; Weisman et al., 2013) acutely respond to father-child interactions, whether these changes are associated with the patterning of later paternal behavior remains largely unanswered. One study showed that T decreases to a challenging lab-based father-infant interaction predicted subsequent positive paternal behavior within the same visit (Kuo et al., 2016). However, it is unknown whether reactivity relates to paternal behavior on a longer time scale, such as months.

While the biobehavioral synchrony model includes a focus on the influence of short-term hormonal changes on behavior (Feldman, 2012a, b), evolutionary-oriented theoretical frameworks, particularly life history theory (Gettler, 2014; Gray et al., 2017; Kuo and Gettler, 2019; Stearns, 1992), are commonly drawn on in studies of human paternal psychobiology to frame why men have the biological capacity to respond to invested partnering and parenting and what the functional implications are, from an adaptive perspective. According to life history theory, individuals must allocate limited resources (time and energy) to growth, reproduction, and survival, which are considered mutually exclusive demands. As biological mechanisms that influence energetic allocation and behavioral processes, hormones help to mediate tradeoffs between demands within different life history strategies. Humans have evolved a life history strategy in which fathers commonly

cooperate with mothers to raise young, which is atypical among mammals (Saltzman and Ziegler, 2014). Cross-species comparisons indicate it is likely that human male physiology has been adaptively selected to help promote parenting effort and shift fathers away from mating effort among committed males (Gettler, 2014; Rosenbaum and Gettler, 2018; Storey and Ziegler, 2016). For example, among vertebrate species that have evolved bi-parental care, higher T is generally linked to a mating-oriented strategy, while lower T is typically associated with a parenting-oriented strategy (Gettler, 2014; Gray et al., 2017; Kuo and Gettler, 2019; Saltzman and Ziegler, 2014; Storey and Ziegler, 2016; Wingfield et al., 1990). Both reactivity and basal shifts in endocrine function are commensurate with tenets of life history theory, including that hormonal shifts may precipitate functional behavioral changes, such as men's fathering behaviors during their transition to parenthood.

However, much of the research on human paternal physiology has focused on the relationships between basal hormone levels and paternal behavior, as indicators of longer-term, more stable shifts in behavior and the underlying physiology of men's life history strategies. Drawing on this framework, multiple studies have found that fathers with lower basal T engage in more childcare, and these patterns are commonly interpreted as reflecting prioritization of parenting effort over mating/competition (Alvergne et al., 2009; Edelstein et al., 2017; Gettler et al., 2015; Gettler et al., 2011b; Kuzawa et al., 2009; Mascaro et al., 2013). There are far fewer studies on basal CORT and paternal behavior but mothers' increased CORT is related to greater interest in infant odors (Fleming et al., 1997), positive maternal attitudes, and approach behaviors toward infants (Mileva-Seitz and Fleming, 2011). Elevations in basal CORT may reflect activation processes which help to orient parents toward infant care and engagement, although chronic CORT elevation could likewise have deleterious effects on parenting, through maladaptive facilitation of prolonged anxiety and other negative impacts on mental health (Erickson et al., 2003). Thus, the timing, duration, and context of elevated basal CORT production are likely critical considerations for the psychobiological effects on parenting. To date, studies of human paternal psychobiology have often operationalized a range of fathering-related experiences (fatherhood status, time allocated to involvement in childcare, observed direct interaction with children, sensory exposure to infant cues) under the singular construct of "paternal behavior" without hypothesizing that different basal hormone and reactivity patterns may support different behavioral competencies within parenting contexts (van Anders et al., 2011). Here, we help to move the field forward by testing whether basal and reactivity hormone measures predict different dimensions of fathering behaviors, specifically, direct care, indirect care, and play.

In this paper we bridge two theoretical perspectives, biobehavioral synchrony (Feldman, 2012a, b) and life history theory (Gettler, 2014; Gray et al., 2017; Kuo and Gettler, 2019; Stearns, 1992), to examine whether short-term hormonal changes during early dyadic interactions and fathers' basal hormone levels predict their later involvement with their infants. Drawing on a large sample of U.S. fathers (N = 298), we first examined whether fathers experienced significant changes in T and CORT while holding their newborns for the first time. We hypothesized that T and CORT would decrease during holding, on average. Second, we assessed whether fathers' T and CORT reactivity to holding their newborns as well as basal levels during their infants' first day postpartum predict later paternal

involvement (direct care, indirect care, and play). Based on life history theory, we hypothesized that greater paternal involvement would be predicted by lower basal T and higher basal CORT. Drawing on the feedback loop concepts proposed in the biobehavioral synchrony model, we predicted that decreases in T and increases in CORT during fathers' initial holding would be correlated with greater paternal involvement months later.

2. Methods

2.1. *Participants and procedures*

Participants were 298 fathers. See Table 1 for participant demographics. All procedures of the current study, which includes both longitudinal and cross-sectional components, were approved by the University of Notre Dame and Memorial Hospital Institutional Review Boards. Inclusionary criteria included that the participant identified as male, was present at the birth, identified as the father of the infant (biological or otherwise), was 18 years of age or older, and that the infant was born at Memorial Hospital in South Bend, Indiana, United States, a UNICEF-designated "baby-friendly" hospital.

A component of the "baby-friendly" procedure is for mothers to engage in skin-to-skin contact with their newborns immediately after birth for 1 h, particularly to help enhance early breastfeeding. After providing informed consent for the study on the birthing unit and following mothers' contact with their infants, fathers were encouraged to hold their newborns for 1 h and given the option to either do skin-to-skin holding (49%) or clothed holding (47%). Eleven men were unable to be coded into the skin-to-skin or clothed holding categories. One participant helped the mother hold the newborn, and the remaining participants ($N = 10$) had missing information about whether they held their infants. Of this group of men, five had hormone data. Holding choice was not significantly related to basal hormone levels or reactivity p 's $> .23$. We collected salivary samples immediately before fathers held their newborns and 1 h later. Given that infants are born at every hour of the day, our sample collection times ranged from 0:02–23:59. On the following day in the Mother-Baby unit, fathers provided two additional saliva samples using the same collection procedures. Sample collection times ranged from 0:23–23:50. The fathers were instructed to collect the samples on the second day at approximately the same time as the first two samples on day one to provide control values that reflected the same time of day as the first sample collection on the day of the infant's birth, without the confound of witnessing the birth. Fathers were also invited to participate in an online follow-up study via Qualtrics to assess paternal psychosocial stress, fathering behavior, parent-infant bonding, and infant temperament. We attempted to collect follow-up data within a 2–4 month time frame, which coincides with early development of parent-infant attachment (Feldman, 2012c). Of the original recruited sample ($N = 298$), 60.2% ($N = 180$) participated in the follow-up study, and 92.7% of responses occurred within 16 weeks of discharge. Twelve fathers completed the follow-up beyond 16 weeks.

Table 1. Descriptive statistics

Variable	<i>M (SD)</i>
Fathers' age (years)	30.84 (5.97)
Infant age at follow-up (weeks)	12.19 (7.30)
Estimated annual household income	75,066.54 (44,331.72)
	<i>N (%)</i>
Parity	
First-time father	136 (47.6)
Experienced father	150 (52.4)
Marital status	
Married	213 (71.5)
Unmarried	74 (24.8)
Residential status	
Residing with infant's mother	282 (94.6)
Race and ethnicity	
Asian	2 (0.7)
Black/African American	23 (8.2)
Multi-racial	16 (5.7)
Native American	1 (0.4)
White	237 (84.9)
Hispanic/Latino	16 (5.6)
Infant sex	
Female	133 (49.4)
Male	136 (50.6)
Fathers' education level	
< 4-year college degree	155 (57.0)
4-year college degree	73 (24.5)
> 4-year college degree	44 (14.8)

2.2. Saliva collection and assays

Participants provided saliva samples via the passive drool method into polypropylene tubes. Samples were immediately frozen in a -20°C freezer and transported frozen, generally within 7–14 days of collection, to a -80°C freezer at the Hormones, Health, and Human Behavior Laboratory at the University of Notre Dame for storage until analysis. Samples were shipped on dry ice to Salimetrics (Carlsbad, California), where they were assayed for T and CORT using ELISA procedures designed for saliva. CORT in saliva is highly correlated to levels of free (unbound) CORT in circulation (Hellhammer et al., 2009), including for the kits used in the present study ($r = 0.9$; Salimetrics LLC). Acute changes in salivary CORT also closely parallel shifts in circulation within minutes (Vining et al., 1983) and over the time frame of our prepost design (Gozansky et al., 2005; O'Connor and Corrigan, 1987). Salivary T is similarly highly correlated to circulating free levels of T, particularly for males (Arregger et al., 2007; Fiers et al., 2014), including using the present kits ($r = 0.9$; Salimetrics

LLC). The inter-assay coefficients of variation (CVs) for the low and high control values for T were 13.6% and 10.1%, respectively. The intra-assay CVs for T were 6.7% (low) and 2.5% (high). For CORT, the inter-assay CVs were 8.3% (low) and 9.4% (high) while the intra-assay CVs were 5.0% (low) and 4.0% (high).

2.3. Paternal involvement

Fathers estimated their percentage of involvement (0 to 100%) in infant care tasks (versus mother or other caregiver) using the Childcare Activities Scale (Cronenwett et al., 1988). Fathers reported on their involvement in direct care (8 items, $\alpha = 0.65$, e.g., “Bathing child,” “Dressing child”), indirect care (7 items, $\alpha = 0.55$, e.g., “Arranging babysitting,” “Washing child’s clothes”), and play (6 items, $\alpha = 0.80$, e.g., “Playing actively with child”). We note that the indirect care behaviors in the Childcare Activities Scale do not involve activities such as provisioning/breadwinning, acquisition of territory and resources, or protection (Kleiman and Malcolm, 1981). Those behaviors are often important aspects of paternal care in many human societies as well as nonhuman animals and are frequently associated with the phrase “indirect care” in some fields.

2.4. Statistical analyses

Hormone data were first inspected for outliers, with particularly elevated values possibly indicating blood contamination. CORT values above $2.00 \mu\text{g/dL}$ were > 5 SD from the mean and removed from analyses ($N = 3$). CORT outlier values were from both days, including both time points on day 2 but only pre-holding from the day of the birth. CORT values were then natural log-transformed to correct for positive skew, and transformed values were used in subsequent analyses. T values above 300 pg/mL were > 5 SD from the mean and also excluded from analyses ($N = 3$). All T outlier values were from the day of the birth. One participant had outlier values for both pre- and post-holding time points, and the other outlier came from the pre-holding time point. We removed the effect of time of day from hormone values by regressing each hormone value onto time of day, taking the unstandardized residuals and then adding them back to the mean of each hormone value. These residualized hormone values were used for hypothesis testing. We operationalized the basal measure as the first sample collected from each day (day of infant’s birth, and second day), particularly to focus on fathers’ hormone levels before physical contact with their infants on the birthing unit. Because witnessing the infant’s birth may have particularly influenced basal T and CORT on the first day, we kept the birth day and second day basal samples as separate basal measures. The second day basal measure was operationalized as a control basal measure.

To test our first question of whether fathers’ T and CORT significantly changed during their initial holding of their newborns, we conducted linear mixed models with full information maximum likelihood to handle missing data. Time point (pre- and post), day (birth day and second day/control), and the two-way interaction between time point and day were modeled as categorical fixed effects. Fathers’ marital status (married vs. single) and parity (first-time father vs. experienced) as well as infant sex (male or female) were modeled as categorical covariates, while fathers’ age was treated as a continuous covariate. T and CORT levels were modeled in two separate models.

To test our second question of whether individual differences in T and CORT basal levels and reactivity to father-newborn holding predicted later paternal involvement, we conducted a multivariate regression with full information maximum likelihood to address missing data. Reactivity was computed as (post-holding sample value – pre-holding sample value) for T and CORT, respectively. Both basal and reactivity T and CORT measures were modeled together. See Table 2 for a correlation matrix of paternal involvement and main hormone variables as well as their means and standard deviations. Fathers' age, infant's sex, parity and marital status were included as covariates.

Table 2. Correlation matrix of father involvement and main hormone variables with means and standard deviations

	1	2	3	4	5	6	7	8	9
1. Direct care	—								
2. Indirect care	0.33***	—							
3. Play	0.43***	0.51***	—						
4. Birth day basal T	–0.07	0.13	0.15 [†]	—					
5. T change while holding	0.17*	0.05	0.03	–0.45***	—				
6. Second day basal T	–0.14	–0.03	0.07	0.37***	0.01	—			
7. Birth day basal CORT	0.13	0.20*	0.14 [†]	0.48***	–0.29***	0.16*	—		
8. CORT change while holding	0.10	0.13	0.17*	–0.18**	0.52***	0.00	–0.45***	—	
9. Second day basal CORT	0.16 [†]	0.11	0.16 [†]	0.22**	–0.03	0.49***	0.27***	–0.03	—
Mean	23.99	27.35	35.78	80.10	–3.31	90.16	–2.23	–0.30	–2.34
(Standard deviation)	(12.09)	(13.71)	(13.36)	(32.26)	(24.86)	(37.36)	(0.80)	(0.69)	(0.73)

Note: CORT values are natural-log transformed.

[†] $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$

3. Results

3.1. Hormone changes during first holding

3.1.1. Cortisol

There was a significant main effect of time point, which was further qualified by a significant time point \times day interaction. See Table 3 for transformed means and 95% CIs in $\mu\text{g/dL}$. Fathers had significantly higher CORT at the first time point compared to the second time point, $F(1, 414.61) = 23.77$, $p < .001$, partial $R^2 = 0.05$. Post hoc pairwise comparisons within the significant time point \times day interaction, $F(1, 414.62) = 23.44$, $p < .001$, partial $R^2 = 0.05$, revealed that CORT levels were significantly higher at the first time point on day 1 compared to day 2, $p < .05$, partial $R^2 = 0.02$, and significantly lower at the second time point on day 1 compared to day 2, $p < .01$, partial $R^2 = 0.04$. Further, fathers' CORT significantly declined during first holding of their infants on day 1, $p < .001$, partial $R^2 = 0.11$, but no significant change was observed for day 2. Additionally, first-time fathers had significantly higher CORT levels than experienced fathers, $F(1, 216.56) = 4.76$, $p < .05$, partial $R^2 = 0.02$. Marital status, fathers' age, infant's sex, and day were not significant.

Table 3. Means and 95% confidence intervals for the cortisol linear mixed model

	Baseline	2nd sample
Infant's birth day	0.11 ^{a1} (0.10; 0.12)	0.08 ^{b1} (0.07; 0.09)
Control day (2nd day)	0.10 ² (0.09; 0.11)	0.10 ² (0.08; 0.11)

Note: Mean values are transformed from natural logged cortisol values and appear in $\mu\text{g/dL}$. Lettered subscripts indicate significant between-time point differences within sampling day at $p < .05$. Numbered superscripts indicate significant between-sampling day differences within time points.

3.1.2. Testosterone

Fathers' T was significantly higher on the second day ($M = 94.39$ pg/mL, $SE = 2.57$ pg/mL), compared to the day of the infant's birth ($M = 82.18$ pg/mL, $SE = 2.48$ pg/mL), $F(1, 211.60) = 24.10$, $p < .001$, partial $R^2 = 0.10$. Married men ($M = 82.01$ pg/mL, $SE = 2.19$) had significantly lower T than unmarried men ($M = 94.57$ pg/mL, $SE = 4.07$ pg/mL), $F(1, 223.90) = 24.10$, $p < .001$, partial $R^2 = 0.03$. There were no significant effects of time point, parity, fathers' age or infant's sex. The interaction between time point and day was also not significant.

3.2. Predicting paternal involvement from basal and reactivity hormone measures

The main predictors of interest were fathers' basal T and CORT levels on the day of the birth, T and CORT reactivity to infant holding, and basal T and CORT levels on the control day (second day after the birth). Parity, marital status, father's age, and infant sex were included as covariates. See Table 4 for full results.

Table 4. Multivariate regression models predicting fathers' post-partum involvement from measures of their testosterone (T) and cortisol (CORT)

Variable	Direct	Indirect	Play
Birth day basal T	-0.04	0.15	0.17
T change during holding	0.14	0.07	0.03
Birth day basal CORT	0.25*	0.25*	0.27*
CORT change during holding	0.20	0.31**	0.26*
Control basal T	-0.28**	-0.33**	-0.14
Control basal CORT	0.18	0.25*	0.13
Parity ^a	-0.34***	0.00	-0.19*
Marital status ^b	-0.04	-0.27**	-0.05
Fathers' age	-0.17	0.03	-0.08
Infant's sex ^c	-0.01	-0.10	-0.22**
R-squared	0.35***	0.26***	0.27***

Note: Standardized coefficients presented.

^a Parity, 0 = first-time father, 1 = experienced father

^b Marital status, 0 = unmarried, 1 = married

^c Infant's sex, 0 = female, 1 = male

* $p < .05$, ** $p < .01$, *** $p < .001$

3.2.1. *Direct care*

Fathers with higher basal CORT on the day of the birth reported greater involvement in direct care ($p < .05$). In contrast, fathers with lower basal T on the second day were more involved with direct care, $p < .01$. First-time fathers were more involved in direct care of these infants than experienced fathers, $p < .001$.

3.2.2. *Indirect care*

Men with higher levels of basal CORT on the day their infants were born and the second day reported greater involvement in indirect care at follow-up, $p's < .05$. Fathers with lower levels of second-day basal T were more involved in indirect care, $p < .01$. Fathers whose CORT increased more while holding their infants on the birthing unit reported greater involvement in indirect care, $p < .01$. Married fathers also were less involved in indirect care than unmarried fathers, $p < .01$.

3.2.3. *Play*

Fathers with higher levels of basal CORT and increases in CORT on the day of infant's birth (while holding) were more involved in play at follow-up, $p's < .05$. First-time fathers were more involved in play with their infants than experienced fathers, $p < .05$, and fathers played more with daughters than sons, $p < .01$.

4. Discussion

The aims of the current study were to: (1) evaluate fathers' changes in T and CORT while holding their newborns for the first time and (2) assess whether fathers' T and CORT responses to holding their newborns as well as basal levels during their infants' first days of life predicted fathers' postpartum involvement in direct care, indirect care, and play with their infants. A key aspect of this study's design was to evaluate whether reactivity or basal measures predicted different categories of fathering activities and to help elucidate previously unclear hormone-behavior relationships and theoretical distinctions on the influence of basal or reactivity measures in parental neuroendocrinology.

Our findings for hormone changes during fathers' holding of their newborns support previous research that pleasant or playful father-child interactions are associated with declines in fathers' CORT (Gettler et al., 2011a; Gray et al., 2007; Saxbe et al., 2014; Storey et al., 2011; Weisman et al., 2013) but elicit no significant changes in T (Gettler et al., 2011a; Gray et al., 2007; Kuo et al., 2016; Storey et al., 2011). Taken together, it appears that a dampening of fathers' CORT production tends to occur, on average, during non-stressful interactions with infants and toddlers such as play or holding, as in our study, but no similar group-level pattern is typically seen for T reactivity.

Here, we bridged the biobehavioral synchrony model (Feldman, 2012a, c) with life history theoretical perspectives to examine how hormone reactivity and basal profiles may predict men's parenting behavior (Gettler, 2014; Gray et al., 2017; Kuo and Gettler, 2019; Stearns, 1992). Our results evinced that this dual-approach explained associations between CORT and later paternal behavior, but this was not the case for T. Basal T, but not T reactivity to father-infant interactions, predicted later paternal involvement. Thus, the results

for T generally align with life history theory-based perspectives in this area that emphasize the importance of longer-term changes in hormones that support shifts in reproductive effort. Previous research has often been indiscriminate in applying these theoretical frameworks across different hormonal systems and, to some extent, various time frames over which hormones could plausibly shape men's parenting and parent-child relationships. Our results suggest that greater specificity is required in theorizing the relationships between basal or reactivity CORT and T measures with paternal behavior.

We also found temporal (day 1 vs. day 2) differences in the hormonal associations with the three dimensions of paternal behavior that we measured. Basal T measured on the control day was predictive of several forms of involvement. Specifically, fathers with lower basal T on the control day reported that they engaged in higher levels of direct and indirect care at follow-up. We did not observe a similar relationship for fathers' play, which is often considered to be more pleasurable than, for example, changing diapers or doing children's laundry. Basal T on the day of the infant's birth, however, was not significantly predictive of later paternal involvement. Basal T on the day of the infant's birth likely represented atypical levels in response to witnessing the infant's birth, rather than typical basal levels. We speculate that these atypical levels in the context of momentous occasions may not be indicators of day-to-day T values that are likely to relate to paternal involvement. The control day results complement a growing body of literature that lower basal T is concurrently related to greater engagement in childcare (Alvergne et al., 2009; Gettler et al., 2015; Gettler et al., 2011b; Kuzawa et al., 2009; Mascaro et al., 2013). Our findings also complement recent work by Edelstein et al. (2017), which demonstrated that greater declines in men's basal T during their partners' pregnancies predicted greater postpartum involvement in childcare. Based on psychobiological frameworks relating T to social behavior in humans (Gettler, 2014, 2016; Gray et al., 2017; van Anders, 2013), it is possible that reduced production of basal T across partners' pregnancies, including around the birth of the infant, helps to attune men to the needs of their infants and the demands of family life, facilitating increased investments in some forms of both direct and indirect parenting effort. Because we measured childcare involvement several months after our assessment of basal T, our study is among the first to show that fathers' basal T predicts later paternal behavior.

Fathers' basal CORT on the day of the infant's birth was predictive of later paternal involvement across the three different dimensions, but basal CORT on the control day was only significantly predictive of indirect care. One possible explanation for these results that we suggest merits future testing is that fathers' circulating levels of CORT immediately prior to the birth of the infant may be indicative of how fathers' HPA axes will activate during challenging and unpredictable moments during the early post-partum, focusing men's attention and mental energy toward parenting effort. These results complement previous work showing that elevated CORT is associated with greater expression of certain maternal behaviors (Mileva-Seitz and Fleming, 2011). Although fathers' CORT declined during holding, on average, across the sample, there was substantial inter-individual variability in whether fathers' CORT increased or decreased. Fathers' larger CORT increases during holding predicted more involvement in indirect care and play but not direct care. Perhaps these increases reflect other biological processes that help to increase attention toward the infant (Feldman, 2012a), but it is unclear why CORT reactivity would predict

indirect care and play specifically. One of the limitations of this study is that we did not assess characteristics of the father-infant interaction on the birthing unit. Although we recorded whether fathers engaged in skin-to-skin or clothed holding, which was not significantly related to T or CORT, we did not record information about the infant. Some newborns may have been crying, while others may have been sleeping. It is plausible that fathers' larger increases in CORT in response to stimuli such as infant crying are correlated with some avoidance to infant distress. Hence, such fathers could exhibit greater involvement in indirect care tasks, which does not involve dyadic interaction with the infant, and play, which would be more likely to elicit infant positive affect. More research is needed to shed light on how CORT reactivity, including in response to variable stimuli/interactions, may relate to different domains of paternal behavior.

Finally, experienced fathers (i.e., non-first-time fathers) were less involved in direct care of and play with their infants than first-time fathers. While experienced fathers often contribute to care for their newborns along with their firstborns or older children, they are likely more involved in the care of their older children than the infants (Kuo et al., 2017). Married fathers were also less involved in indirect care than unmarried fathers, potentially because married mothers may shoulder relatively more responsibilities in indirect child-care tasks. Interestingly, fathers reported playing more with daughters than with sons, which complements some recent findings that fathers are more sensitive with infant daughters than infant sons during play (Kuo et al., 2016).

Our study's design allowed us to capture fathers' hormone levels and changes thereof in response to the first interaction with their newborn. Because our hormonal sampling followed a pre-post design, our measures of basal CORT are limited in comparison to other more robust diurnal measures. However, given the unpredictability of timing of labor and birth, it would have been very challenging to capture fathers' diurnal CORT within this design, in which our point of initial contact and recruitment with the families was when they came to the hospital for the birth. Furthermore, although our basal CORT measure is suboptimal, previous studies using single-time measurements of CORT have found significant associations with maternal behaviors (Fleming et al., 1997; Mileva-Seitz and Fleming, 2011), lending additional support for our findings. Future research could investigate whether diurnal and more robust measures of basal CORT in the infant's early neonatal period are predictive of later paternal behavior. Our indirect care measure did not capture fathering behaviors related to provisioning, competition, or protection, which are often conceptualized as indirect care (Kleiman and Malcolm, 1981). Thus future research could include measures that specifically assess provisioning and protection to investigate whether the hormonal associations we found with our indirect care measure are similarly related to these different behavioral components of parenting effort and cognitive orientations toward them (i.e., feeling highly protective). We also note that we only asked fathers to report on their involvement with the target child only and did not account for their involvement with any other children. Future research could examine how fathers' hormones may be related to involvement across different children. Finally, along with these collective design-based limitations, the sample for our study included relatively few men who were not residing with the infant's mother ($N = 9$; $< 6\%$ of the sample), all of whom were unmarried. Meanwhile, all other men were cohabitating. It is relatively unknown

how important co-residence with a pregnant partner is for men's physiological function as they transition to parenthood, but past work hints that it could be significant, along with residence with mothers and children after birth (Edelstein et al., 2017; Gettler et al., 2015; Saxbe et al., 2017). In the present study, given the small cell sizes of cohabitation status and that marital status appeared to account for differences in cohabitation status for T, we included marital status instead of cohabitation status as a covariate. These life history and residence status issues are important considerations for future work.

5. Conclusions

This was the first study to examine how hormonal changes during fathers' first interaction with their newborns predicted later paternal involvement across different dimensions. Lower basal levels of T appear to be related to direct and indirect parenting effort but not play. Elevated basal CORT around the time of birth and increased short-term production during the earliest stages of father-child interaction predicted greater paternal involvement in various dimensions of care. Our results provide novel and complementary findings on the psychobiological dynamics of human fatherhood in the early post-partum, including immediately around birth, and in terms of hormone-specific patterns related to fathers' later parenting, measured via multiple temporal perspectives (i.e., basal and reactivity profiles). Consequently, our study enhances our understanding of the utility of life history theory and biobehavioral synchrony models in making predictions for CORT and T within paternal neuroendocrinology.

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